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REVIEW ARTICLE

Appropriate technology for domestic wastewater management in under-resourced regions of the world

Nurudeen Abiola Oladoja[1]

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Abstract Centralized wastewater management system is the modern day waste management practice, but the high cost and stringent requirements for the construction and operation have made it less attractive in the under-resourced regions of the world. Considering these challenges, the use of decentralized wastewater management system, on-site treatment system, as an appropriate technology for domestic wastewater treatment is hereby advocated. Adopting this technology helps save money, protects home owners' investment, promotes better watershed management, offers an appropriate solution for low-density communities, provides suitable alternatives for varying site conditions and furnishes effective solutions for ecologically sensitive areas. In the light of this, an overview of the on-site treatment scheme, at the laboratory scale, pilot study stage, and field trials was conducted to highlight the operational principles' strength and shortcomings of the scheme. The operational requirements for the establishing and operation of the scheme and best management practice to enhance the performance and sustenance were proffered.

Keywords Appropriate technology · Domestic wastewater · On-site treatment · Percolator · Water pollution

Introduction

The relatively low gross national product of majority of the developing countries has made investment in social infrastructure to wane and hence shortage of investment in the construction, operation, and management of wastewater treatment technologies prevails, especially in the under-resourced regions. Consequently, the danger inherent in access to unsafe water and poor sanitation abounds. This pathetic scenario was vividly captured by a World Bank report (1998) thus: "microbial diseases—costing billions of dollars in lost lives and unhealthy workers—are endemic in the poorest parts of most cities of the developing world. Where, water sources are contaminated and sanitation facilities are minimal or non-existent. Where, rats, flies and mosquitoes abound, thyphis, dysentery and encephalitis are among the scourges of the poor". Unfortunately, this same scenario persists in most part of the under-resourced regions of the world until the present-day. The tail end of last century witnessed an array of programs, designed for the alleviation of the global water and sanitation problems. The first of such programs, dubbed International Drinking water supply and Sanitation Decade (1981–1990), aimed at providing water and Sanitation for all by 31st December 1990. This was followed by safe water 2000, with water and sanitation for all by 31st December 2000. And now we have an unnamed target of water and sanitation for all by 31st December 2025, with the interim target of halving the number of those without adequate water and sanitation by 2015 (Mara and Feachem 2001).

Centralized wastewater treatment system (e.g. activated sludge, trickling filter, oxidation pond integrated biological/chemical system, rotatory biological contactors, etc.) (Fig. 1) is the modern waste management practice, which is based on gradual reduction of wastes, with the ultimate aim of eliminating those that have negative impact on the environment. The practice operates on the principle of reuse, recycle, and recovery. Albeit this wastewater management practice is effective, the associated cost and the stringent requirement for the construction and maintenance

✉ Nurudeen Abiola Oladoja
bioladoja@yahoo.com

[1] Adekunle Ajasin University, Akungba Akoko, Nigeria

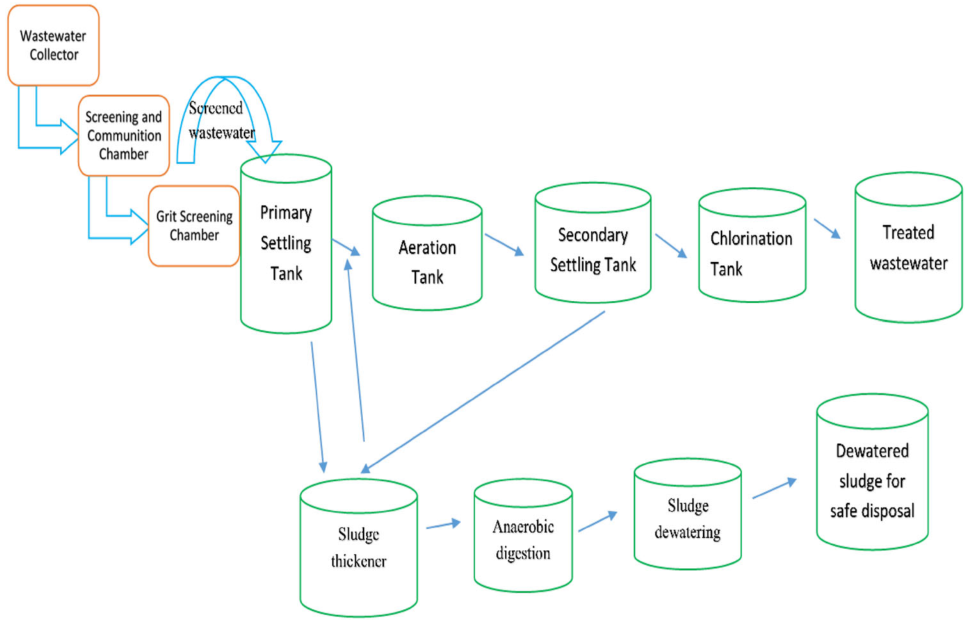

Fig. 1 Schematic representation of a typical centralized wastewater treatment system

have made its use to be less attractive in the under-resourced regions. In order to assuage the scourge from lack of access to potable water, this under-resourced regions require the use of high-performance, economical, technologically simple, reliable, low-energy consuming decentralized wastewater treatment technology to control pollution in the water environment and to alleviate the serious escalating water shortages that have been caused by water pollution in recent years. Adopting the definition of Douglas (1998), decentralized wastewater management employs all available treatment and disposal technologies. The appropriate technologies, in a measure that meets current needs and takes into consideration future growth, are matched with the treatment and disposal requirement that have been identified. According to the report sent to the Congress by the U.S. Environment Protection Agency (1997), using decentralized wastewater treatment system saves money, protects the home owner's investment, promotes better water shed management, offers an appropriate solution for low-density communities, provides suitable alternative for varying site conditions, and furnishes effective solutions for ecologically sensitive areas.

In the present treatise, the concept of appropriate technology shall be presented and the basic operational principles, the acceptability, efficiency, and sustainability of the conventional centralized domestic wastewater treatment options shall be discussed. Progress in on-site decentralized treatment methods, as appropriate technology for domestic wastewater treatment, shall be presented, under the broad categories of targeted pollutants (i.e. physicochemical characteristics, nutrients, and micropollutants). The operating requirement and the management strategies for efficient operation of the system shall be discussed.

The concept of appropriate technology

The Indian ideological leader, Mahatma Gandhi, is often cited as the "father" of the appropriate technology movement. Though the concept was not given the name then, it was proposed for small, local, and predominantly village-based technology to help Indian's villages become self-reliant. He disagreed with the idea of technology that benefited a minority of people at the expense of the majority or that put people out of work to increase profit (Akubue 2011). During the reign of Mao Zedong and the ensuing Cultural Revolution, China also implemented policies similar to appropriate technology. In this era, development policies based on the idea of "walking on two legs" advocated the development of both large-scale factories and small-scale village industries (Akubue 2011). The nuances of appropriate technology vary between fields and applications; it is generally recognized as encompassing technological choice and application that is small-scale, decentralized, labor-intensive, energy-efficient, environmentally sound, and locally controlled (Hazeltine et al. 1999). The present day advocates of appropriate technology also emphasize the technology as people-centered. Appropriate technologies are sometimes used and promoted by advocates of sustainability and alternative technology. Thus, features such as low cost, low usage of fossil fuels, and use of locally available resources can give some advantages in terms of sustainability (Sianipar et al. 2013). Well-known examples of appropriate technology applications include bike- and hand-powered water pumps (and other self-powered equipment), the universal nut Sheller, self-contained solar-powered light bulbs and streetlights, and passive solar building designs.

In water treatment operations appropriate technology has been applied at community-scale and household-scale point-of-use (POU) designs. Some appropriate technologies that have been used in water supply measures and treatment include the following:

1. Deep wells with submersible pumps in areas where the aquifers are situated at depths >10 m.
2. Shallow wells with lined walls and covers.
3. Rainwater harvesting systems with appropriate storage method, especially in arid regions.
4. Fog collection system; suitable for areas which experience fog even when there is minimal rainfall.
5. Air well, a structure or device designed to promote the condensation of atmospheric moisture.
6. The hippo water roller and Q-drum which allow more water to be carried, with less effort and serve as a good alternative for ethnic communities that do not wish to give up water gathering from remote locations, assuming low topographic relief.
7. The roundabout playpump, developed and used in southern Africa which harnesses the energy of children at play to pump water.
8. Treatment ponds and constructed wetlands which help to purify sewage and Greywater.

Domestic wastewater management—the conventional approach

Domestic sewage is made up of human waste (feces and urine) and sullage. Sullage, which is also known as Greywater, is wastewater arising from personal washings, laundry, food preparation, and cleaning of the kitchen utensil. Owing to the dependence of domestic wastewater on household activities, its main characteristics strongly depend on factors such as cultural habits, living standard, household demography, type of household chemicals used, etc. The data presented in Table 1 are the results of the analysis of representative samples of domestic sewage in some selected cities (Ibadan, Lagos and Benin-City) of an African country, Nigeria.

A fresh sewage is a grey turbid liquid having earthy but inoffensive odor. In all hot climate areas of the world, sewage loses its content fast and offensive odor ensues. This sewage ultimately empties itself into a receiving water body and the water is polluted. Sewage affects water bodies in three ways. First, it contributes organic matter: organic forms of nitrogen and phosphorus, some of which stimulate the growth of organism which may use up the available oxygen in water. Second, it adds intestinal bacteria (coliform) along with other pathogens which have to be eliminated if the water is to be abstracted for domestic use. Third, it may add hard detergents of alkyl benzene sulphonate (ABS) base which causes river to foam. When all these occur, water quality deteriorates fast, aquatic life forms may die, and the water stinks. In the under-resourced regions of the world, aside the human waste which is given special management attention, sullage is not considered as a threat; hence it is discharged without recourse to any treatment option. The apathy towards the management of sullage is more pronounced amongst the low-income strata of the populace in urban and peri-urban settings of the under-resourced regions. The sullage is discharged untreated into stormwater drains or sewers, where this facility is available, from where it flows into aquatic system or forms a pool that constitutes eye sore and a breeding place for mosquitoes, rats, flies, and pathogens. Typical methods of discharging wastewater emanating from a domestic source that is practiced in the under-resourced regions are presented in Fig. 2a, b.

In the middle- and high-income strata of the urban settings of the developing world, domestic sewage is managed by a number of conventional wastewater treatment systems presented below. The details of the operational features, challenges, and benefits of the conventional domestic wastewater treatment systems are presented in Table 2.

Cesspools

It is an underground chamber constructed solely for the reception of and storage of wastewater with no treatment taking place. Cesspools are required to be watertight and constructed so as not to overflow. They are not septic tanks and so no treatment occurs. They are normally used for single dwellings or small group of houses. They can be constructed from a variety of different materials including concrete, plastic, and fiber glass, although fabricated units must be set in concrete. Cesspools are only used where no other form of treatment is possible, and the need to have them regularly emptied means they are amongst the most expensive form of treatment for domestic dwellings in terms of both capital and operational cost

Septic tank

Septic tank is a common domestic treatment facility in the developing world. It performs a primary treatment of sewage before it is discharged through a soak-away. It has been used as a pretreatment system for disposal of domestic sewage where it is used in conjunction with an effluent soak-away system. It can also fulfill a role as primary treatment device at small sewage treatment plants. The function of the tank is to receive wastewater, separate

Table 1 Results of the characterization of representative samples of domestic sewage from cities of a developing nation (Nigeria) (Ademoroti 1986)

Characteristics	Lagos	Ibadan	Benin
T°C	24.5–29	24.5–28.0	24.5–27.5
pH	6.8–7.3	6.8–7.5	6.5–7.4
TSS (mg/L)	119.8–232.0	120.3–228.0	119.3–223.5
BOD (mg/L)	208.0–310.5	204.2–319.8	201.0–318.0
COD (mg/L)	353.6–541.8	347.1–543.7	341.7–540.6
Ammonia-N (mg/L)	13.6–18.2	13.8–17.7	13.8–18.3
Nitrate-N (mg/L)	0.4–1.6	0.0–1.0	0.0–0.75
Phosphate-P (mg/L)	3.5–13.8	16.5–21.4	19.8–25.6
Detergents (ABS base) (mg/L)	19.2–23.6	16.5–21.4	19.8–25.6
Total coliform/100 mL sample	$(94.0–4.8) \times 10^7$	$(4.3–4.7) \times 10^7$	$(4.9–5.2) \times 10^7$

Fig. 2 **a** Discharge of wastewater from bathroom in a Peri-Urban System. **b** Discharge of wastewater from the kitchenette

solids from the liquid, provide limited digestion of the solids, and allow the liquid to discharge for further treatment or disposal. The soak-away system allows the effluent to seep into the ground. (ENSIC 1982). Despite the general acceptability of this treatment facility in the management of sewage from domestic source, septic tank effluents have been reported to be high in suspended solids, BOD, bacteria, and phosphorus. As a process, sedimentation alone is not highly effective in removing pollutants and the septic tank is subject to interference from other processes. Separation of sedimentation and sludge digestion led to the development of the "Imhoff tank". This two-storeyed tank has proved useful at community sewage treatment plants but its cost and daily maintenance requirements detract from its use on a household scale. Attempts to improve on septic tank tend to result in units which are more expensive to install and require increased operational input. These improved versions tend to move away from the concept of a cheap, relatively maintenance-free unit.

Small complete treatment system

Secondary treatments are often used with septic tanks to treat the final effluent before disposal and include percolating filters, rotating biological contactors, and increasingly, reed beds (Upton and Green 1995). However, there are a wide range of small packaged systems available for the treatment of domestic effluent from single or several houses. These are largely based on fixed film or activated sludge systems.

On-site water treatment systems

Ideally, domestic wastewater treatment systems are required to be cheap, robust, compact, hygienic at site, odorless, require little maintenance, and be installed, and operated with ease (Gray 1999). On-site treatment of waste is a decentralized wastewater treatment system that requires simple, reliable, low-energy consuming and low-

Table 2 Features of the conventional domestic wastewater treatment systems

Treatment system	Operational features	Challenges	Benefits
Cesspools	1. Reception and storage of wastewater 2. No treatment takes place 3. Suitable for single dwellings or small groups of houses	1. Requires regular emptying 2. High capital and operational cost 3. High cost of system discharge 4. Tasking and expensive construction of underground storage	1. No power requirement 2. No quality control is required 3. Simple operational mechanism that hardly goes wrong 4. Safe from the danger of intermittent usage 5. No immediate negative environmental impact
Septic Tank	1. Provide partial treatment 2. Suitable for individual houses and small communities 3. Achieves 40–50% BOD removal and 80% TSS removal	1. Leaking joints often cause groundwater contamination 2. Non-desludging cause poor effluent quality 3. Thick scum or sludge layer blocks outlet pipe	1. No power requirement 2. Limited quality control 3. Safe from the effects of intermittent usage 4. It has very small head loss
Small Complete Treatment System	1. Combination of secondary treatment method with septic tank 2. Effluent of higher quality characteristics are produced	1. Service checks are often required 2. The design and specification are constantly changing	1. Often requires the use of electricity 2. Disinfected and nitrified effluent is produced 3. System often possesses inbuilt diagnostic alarm system

cost technologies that private owners with little skills for operations can afford (Schudel and Boller 1989). The choice of an on-site system for domestic wastewater management is dependent on the raw water physicochemical characteristics and end use. Thus on-site treatment of domestic wastewater could be said to be specific. The primary objective of domestic wastewater treatment is to protect public health and the environment in a socio-culturally and economically sustainable manner. Management systems should also account for the willingness and ability of users to operate their own system (user-friendliness) and comply with relevant legislation and regulations.

In the developed world, the use of on-site system is being promoted, as a convention, for the management of domestic wastewater. For example, in the United States, it has been reported that more than 25 million homes, or 25% of the population, use onsite sewage treatment and disposal systems (OSTDS) to meet their wastewater treatment and disposal needs (USEPA 2002). A traditional OSTDS normally consists of three main components: a home's indoor plumbing, the septic tank, and a standard drain field. When properly constructed and maintained, such septic systems can provide a few years of safe, reliable, and cost-effective service (Etnier et al. 2000).

Amongst the array of on-site treatment technologies, gravity percolation of wastewater through a reactive material is a common on-site wastewater treatment technology that has gained wide acceptance. During the transit through the percolator, the wastewater is purified by physicochemical (filtration, adsorption) and biological (microbial degradation) process (Lens et al. 1994). Notable reactive media that has been used in gravity percolation system include slag and ground stones (Oleszkiewicz 1981; Bishop and Kinner 1986), soil materials such as sands (Pell et al. 1984) and organic materials like bamboo (Kirchhof 1989), straw (Lowengart et al. 1993), and sand and gravel (Farnham and Brown 1972; Nicholas and Boelter 1982).

Over the years, different on-site systems have been developed and tailor made to abate specific pollutants (e.g. physicochemical characteristics, nutrients, micropollutants and biological). On the basis of the genre of pollutants found in domestic wastewater, an overview of some of the tailor-made on-site treatment systems amenable for the management of domestic wastewater shall be conducted under three broad categories (i.e. physicochemical characteristics, nutrients and micropollutants). It is noteworthy that these three broad categories of pollutants, enunciated as the main theme of the present treatise, do not constitute the main target of on-site wastewater treatment systems. On-site wastewater treatment systems that attenuate biological pollutants (Pell et al. 1990; Farrell et al. 1990; Lens et al. 1994) and those that operate on the principle of resource recovery (e.g. water, nutrient, energy, precious metal) have been reported in different treatise (Barbosa et al. 2016; Biswas et al. 1999; Oladoja et al. 2013, 2015, 2016; Mackey et al. 2014; Diener 2014).

Physicochemical characteristics

The potential use of bark (*Pinus* spp) and woodchips, two inexpensive and readily available waste products of the wood industry, was assessed as percolator material for the direct treatment of (unsettled) domestic sewage (Lens et al. 1994) in a laboratory study. The main potential for percolators lies in the under-resourced regions of the world, since they can be constructed with simple local logistics. Bark and peat were found to be applicable materials; woodchips seemed inadequate because of poor COD_{tot} removal and lack of disinfection. Matured percolator columns containing a layer of 50 cm bark packed at a density of 0.150 g/cm^3 and supplied with 10 cm wastewater per day gave the following reductions (%): SS, 72; COD_{tot}, 63; BOD_5, 97; NH_4^+-N, 64; and N_{tot}-N, 35. The effluent had a low pH (pH 4.5) during the first 3 months of operation. Once matured, the following average reductions (%) were obtained: SS, 91; COD_{tot}, 50; BOD_5, 99; NH_4^+-N, 93 and N_{tot}-N, 38. The treatment capacity was not significantly affected by the applied densities of a percolator layer (0.075 and 0.100 g/cm^3 for peat and woodchips; 0.150 and 0.175 g/cm^3 for bark) and the hydraulic loading rates (2.5 or 10.0 cm/d).

Combining two or three materials by mixing (equal volume) or by applying them in layers (equal layer thickness) gave similar effluent qualities. On the basis of the results obtained from this study, the authors surmised that the applicability of percolators using organic materials will be rather limited in industrialized countries because of their inferior effluent quality compared to other small-scale wastewater treatment systems. On the basis on the simplicity of construction and low price, the system is still applicable in the treatment of small quantities of wastewater produced at remote sites, in use for only short periods of the year (e.g. camping sites) or to supplement existing pretreatment systems, such as septic tanks and tilted plate separators.

The application of wastewater to organic soil system is an alternative method of treatment and disposal that is receiving increasing attention. Stratified and a Single-layer Laboratory Sand Filter was designed to treat dairy soiled water pretreated with a farm-scale woodchip filter (Ruane et al. 2014). The performance of a single-layer sand filter (SF) and a stratified SF, loaded at 20 L m^{-2} day^{-1}, to polish effluent from a woodchip filter was investigated over a period of 82 days. Average influent unfiltered chemical oxygen demand (COD_T), total nitrogen (TN), ammonium–N (NH_4^+–N), ortho-phosphorus (PO_4^{3-}–P), and SS concentrations of 1,991 ± 296, 163 ± 40, 42.3 ± 16.9, 27.2 ± 6.9, and 84 ± 30 mg L^{-1} were recorded. The single-layer SF decreased the influent concentration of COD_T, TN, NH_4 $^+$–N, PO_4–P, and SS by 39, 36, 34, 58, and 52%, respectively. Influent concentrations of COD_T, TN_T, NH_4–N, PO_4–P, and SS were decreased by 56, 57, 41, 74, and 62% in the stratified SF. The single-layer SF and the stratified SF were capable of reducing the influent concentration of total coliforms by 96 and 95%, respectively. Both types of SFs produced final water quality in excess of the standards for re-use in the washing of milking parlours.

In another development, real-life applications of the organic-soil system, ditched peat lands, have been established in Finland to treat liquid waste from small villages. This method was reported (Kampi 1971; Suraka 1971) to remove from the influent, on the average, about 39% of the phosphorus, 62% of the Nitrogen, 80% of the BOD, and 95–99% of the bacteria.

Oladoja et al. (2006a, b; Oladoja and Asia 2006) fortified some tropical clay minerals with gravel pebbles and used them in the direct treatment of domestic wastewater and industrial effluents (natural rubber processing, brewery, and textile industry). The authors hinged the fortification of clay with gravel pebbles on the fact that the use of soil, as percolator material, is restricted by low permeability and so it is assumed that the gravel fortification of clay would enhance the permeability and thus make it amenable as percolator in on site system. Clays have unusual physico-chemical properties because of the combined influence of two factors—high specific surface area and electrical charge on the basic silicate structure of the clay mineral. These unusual physicochemical properties of clays are responsible for their high adsorptive power and cation exchange capacity, which can be harnessed for domestic wastewater purification. Some of the physicochemical parameters investigated in the treatment system included pH, Solids, Turbidity, COD, BOD, DO, TKN NH_4^+-N, NO_3^-N, and Total Bacteria. Treated effluent with significantly improved physicochemical parameters were obtained from the process

Domestic wastewater was treated using a novel hybrid two-stage vertical flow system that targeted the removal of pollutants such as COD, N, and P simultaneously (Luo et al. 2014). A coarse zeolite trickling filter (ZTF) with low packing height was utilized to adsorb and transform the ammonium as well as to trap and degrade the organic matters to some extent before a multi-soil-layering (MSL) bioreactor was used for further treatment. Zeolite was chosen as the filter media for efficient control of nitrogen in the system because it possesses high ion exchange capacity, advanced porous structure, low density, and good ion exchange selectivity for NH_4^+ (Gottardi 1978). It was assumed that iron was easier to ionize under aerobic conditions and the precipitate would adsorb more efficiently in soil; thus iron scraps were added into the ZTF in addition to the Soil mixture block (SMB) to promote phosphorus removal. The proposed mechanistic details of the pollutant removal process, by the authors (Luo et al. 2014), are presented in Fig. 3. In order to ensure stability of the system, promotion of low maintenance requirements and reduction of clogging probability, artificial aeration of the system was omitted. Simulated septic tank effluent was treated using the on-site system at a loading rate of 440, 640, and 920 L m^{-2} day^{-1}, respectively. Total removal rates (%) of COD, TP, NH_4^+ -N, and TN ranged 90.3–95.2, 92.0–94.0, 85.1–86.9, and 58.9–63.8 with mean final effluent concentrations (mg/L) of 12, 0.28, 5.66, and 21.0, respectively, at mean hydraulic loading rate of 920 L m^{-2} $day^{-1}$and under relatively stable conditions. The system operated without any sign of oxygen shortness even at the maximum loading rate of 250 g COD_{Cr} m^{-2} -$day^{-1}$and 40 g NH_4^+-N m^{-2} day^{-1}without artificial aeration, and clogging did not occur during the study owing to better water dispersion of the MSL. This is an indication that the hybrid system could operate well for COD removal and nitrification with little management and labor demand.

Constructed wetland (CW) is an attractive wastewater treatment system for small communities (<2000 people-equivalents; p.e.) because of the simplicity of operation, low cost, and reliable treatment efficiency (Kadlec 2000). The National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA), France, developed an innovative type of first-stage for vertical flow constructed wetland (VFCW) made of gravel instead of sand. This first-stage type directly accepts raw wastewater, without the need for a preliminary settling tank. In a long-term operation, Molle et al. (2005) recorded on this first stage mean removal efficiencies of up to 80% for COD, 85% for TSS, and 60% for TKN. However, despite recent optimization trials in terms of media depth and aeration,

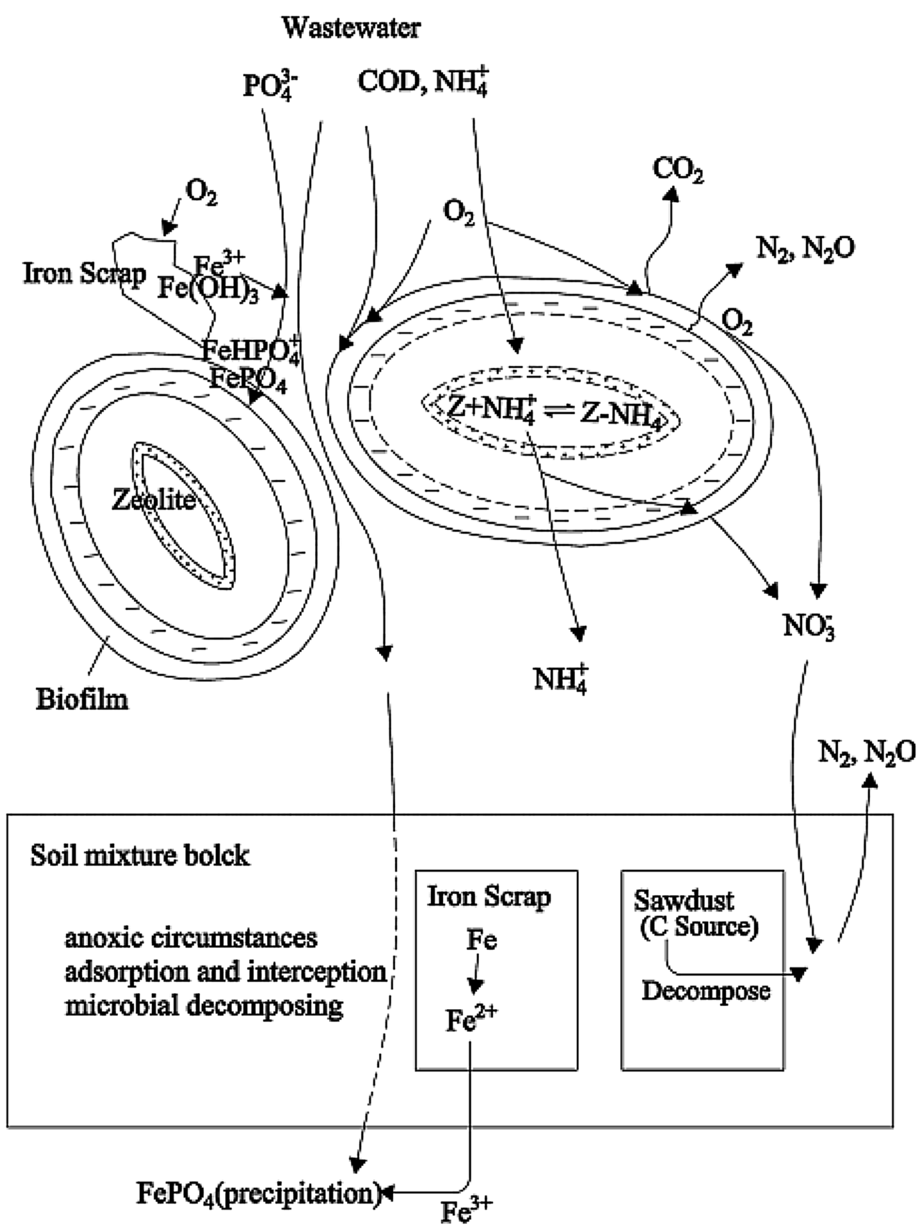

Fig. 3 Proposed Mechanistic details of Pollutant removal (Luo et al. 2014)

the first stage of this VFCW still lacks treatment efficiency, making it necessary to upgrade with a second vertical stage that increases the total surface area needed. Different studies on multi-soil-layering system (MSL), a novel soil-based technology that makes use of the soil to improve the treatment efficiency of the VFCW, have also been reported (Attanandana et al. 2000; Luanmanee et al. 2001, 2002; Masunaga et al. 2007; Sato et al. 2011; Wakatsuki et al. 1993).

Vermifiltration has been recommended as a decentralized treatment option for use in small communities, colonies, and villages because it needs no external energy, except pumping. Small to pilot scale level studies have been carried out on vermifiltration technology which shows a high efficacy for sewage treatment with high attenuation rates of COD, BOD, and SS, as well as the ability to reduce N and P (Sinha et al. 2008). Chemical factors (e.g. pH and ammonia) that may affect the earthworms' survival and their effect on treatment of wastewater have also been studied. The pH in wastewater can be almost neutralized by earthworms and there is very little or no problem of any foul odor during the processing (Sinha et al. 2008; Hughes et al. 2009). Hughes et al. (2009) also reported that ammonia had very low toxicity on the survival of earthworms in vermifilter. The potential of vermifilter using river bed material for the treatment of domestic wastewater, at different hydraulic loading rates, has been investigated (Kumar et al. 2014). Additionally, a comparative study was performed with vermifilter containing the earthworm species (*Eisenia fetida*), parallel to a geofilter (without earthworms) for the enhanced treatment of the wastewater. Synthetic domestic wastewater of medium strength was applied to the vermifilter and geofilter at four different hydraulic loading rates of 1.5, 2, 2.5, and 3.0 m^3m^{-2} day^{-1}. Optimum results were observed in case of hydraulic loading rate of 2.5 m^3m^{-2} day^{-1}. For this hydraulic loading rate, the removal efficiency values (%) of BOD, TSS, and TDS with vermifilter were 96, 90, and 82, respectively, while in geofilter the observed values (%) were 70, 79, and 56, respectively. Consequent upon the quality characteristics of the treated effluent and the vermicompost that met the quality requirement for agricultural applications, the effluent and the vermicompost were recommended for use for irrigation purpose and manure in agricultural practices, respectively.

The technology of effective microorganisms (commonly termed EM technology) was developed in the 1970s by Teruo Higa (1991). The positive influence of EM on minimization of the olfactory noxiousness has been demonstrated, e.g. for leachates from organic waste composting processes (Wichmann and Otterpohl 2009) and a kitchen waste composting process (Masi et al. 2010). Effective microorganism (EM) is a culture of coexisting beneficial microorganism that predominantly consists of lactic acid bacteria, photosynthetic bacteria, yeast, fermenting fungi, and actinomycetes (Mongkolthanaruk and Dharmsthiti 2002). The EM preparation contains numerous enzymes which can decompose the organic matter in an environmentally friendly manner and ensure the survival and growth of the microorganisms both in the soil and in other environmental media (Namasivayam and Kirithiga 2010). In Egypt, the viability and efficiency of different hybrid treatment systems was investigated by Abdel-Shafy et al. 2014. The examined hybrid systems included sedimentation followed by aeration and the EM was added to the sedimentation process for the purpose of enhancing the efficiency of treatment. The process involves monitoring of specific water quality parameter under varying operating conditions in a different sedimentation period, EM doses, and aeration rates to reach the unrestricted water reuse. Grey water treatment was examined first in batch experiments to determine the optimum operating conditions including the settling time, the dose of EM, and the aeration time. The obtained optimum conditions were implemented in pilot plant study. The pilot plant study was examined at both 3.0 and 4.5 h settling time followed by aeration for 90 min; the removal rates (%) were 70.8, 63.1, 70.6, and 63.5 for the TSS, COD, $BOD_{5,}$ and oil and grease, respectively. By increasing the settling time to 4.5 h followed by aeration for 120 min, the final treated effluent was still below the requirements of the ''unrestricted reuse''. In order to enhance the treatment efficiency of the system, EM was added at 1.2 mg/L where the characteristics of the final effluent could cope with the permissible level of the secondary treatment for reuse in irrigation according to the ''Egyptian Guideline''. Further improvement was investigated by increasing the EM dose to 1.5 and the settling time to 4.5 h, followed by aeration for 90 min. The removal rates (%) reached 98.1, 91.1, 96.1, and 96.2 for the TSS, COD, $BOD_{5,}$ and oil and grease, respectively. The Escherichia coli count in the final effluent reached 100 ml/L. Following this treatment, the quality characteristics of the final effluent fell within the permissible limits of the unrestricted water reuse according to ''Egyptian Guideline'' regulations.

In response to Japan's water pollution problem, a low-cost performance system that uses natural materials to treat small foul water outlets or polluted streams was developed. This system helped to reduce concentrations of nutrients, salts, BOD, COD, SS, heavy metals, and synthetic detergents, before they enter larger watercourses (Matsumoto 1998). This system, named Shimanto-gawa, uses only natural materials and no synthetic chemical for the wastewater treatment. Besides the Shimanto-gawa system, another on-site domestic wastewater treatment system, called Johkasous, has also been developed and become popular in Japan. These systems are household-sized units with a capacity of 1–2 m^3 day^{-1}. The system is generally composed of a primary treatment unit (including a primary settling tank or anaerobic filter tank or both); an aerobic biological treatment unit (for example, an activated sludge process, an aerobic submerged biofilter, fluidized bed reactor, or biofilm filtration reactor), and a disinfection chamber (JECES 1999). The guideline for biochemical oxygen demand (BOD) of effluent from Johkasou systems is 20 mg L^{-1}. Johkasou systems including nutrient removal processes have also been developed (Nakajima et al. 1999), and a membrane bioreactor for small-scale plants has been tested (Ratanatamskul et al. 1995).

In Europe, a low-cost treatment technology, known as the Kikuth Reed Bed technology, is being widely used for the treatment of highly contaminated wastewater. The treatment system is designed around soil-based plant and microbiological reed beds. The reed bed system has simple components, which interact in a complex manner to produce an ideal medium for wastewater treatment (Adcock et al. 1999). The 'Kikuth' system made its debut in Europe and it is now being used successfully around the world to treat wastewater (primary, secondary, and tertiary treatment).

In China, a high-performance, low-cost wastewater treatment technology has been established to control pollution in the water environment and to alleviate the serious escalating water shortage that has been caused by water pollution. The system, which is known as Eco-Pond, has a number of positive characteristics such as easy operations, energy efficiency, low capital, and operation and maintenance cost. The pond systems have been used as a popular alternative treatment method in remote and less affluent regions since the 1970s (Wang et al. 2001). In such circumstance, the communities, mainly medium and small cities and towns, could not afford to build and operate conventional treatment works based on the activated sludge process, and willingly sacrificed mainly non-arable land to resolve their water, environmental, and resource problems using the Eco-pond (Wang 1987). The use of ponds, however, has a long tradition in China. The Eco-Pond systems consist of primary treatment, an advanced anaerobic pond with fermentation pits at the bottom, an anaerobic transformation pond, algae/bacterial pond, and fishpond.

Nutrients (i.e. P and N)

Despite the negative impact of the presence of excessive nutrients (i.e. phosphorus (P) and Nitrogen (N)) in the environment, P is an important nutrient that is critically needed for the normal functioning of ecosystems. Effluent from agricultural practice and domestic wastewater remain the main input of P into the environment. In Europe, the supplementary treatment of wastewater from houses and small rural communities specifically designed for P removal is becoming important for the improvement of environmental quality in streams and lakes (Brix et al. 2001). In order to limit the introduction of nutrients into the environment via the domestic source, different reactive sorption media have been tested in on-site system such as percolator system or subsurface flow constructed wetlands. The phosphorus removal potential of the reactive sorption media has been found to be closely associated with the physical, chemical, and hydrological properties of the filter material, because P is mainly sorbed by or precipitated in filter media (Faulkner and Richardson 1989; Kadlec and Knight 1996; Sakadevan and Bavor 1998; Vymazal et al. 2000). Because phosphorus is removed either by sorption and or precipitation processes, Ca, Fe, and Al content is important in efficient P removal. A great variety of different types of materials for P retention in CWs were published by Vohla et al. (2011).

Baker et al. (1998) surmised that the primary benefit of a treatment system including a P-retaining substrate is that it can achieve desired levels of P-attenuation regardless of site conditions. They also stressed that such a system can also accumulate P in a finite and accessible volume of filter media, thus making the material available for collection. This implies that the substrate is placed in the system in such a way that it would be easy to replace, when saturation is achieved. Baker et al. (1998) have suggested a number of placements of filter media in different kinds of on-site treatment systems. They suggested, for instance, a filter media be placed as a horizontal treatment layer within conventional septic system tile beds, incorporation of the filter media as a module after primary treatment or filter media installed as a treatment barrier. Another possibility is to use the substrate as bed media in a CW, which has been suggested by several researchers and also investigated by several scientists. Also, from another practical point of view, substrata-based systems are preferred to soil-based ones. Mann (1990) stressed that filter substrates are more advantageous to use due to their high hydraulic conductivity, e.g. they are less likely to clog or block than are systems based on soil containing high levels of clay or silt. This is of importance because hydraulic conductivity affects the P sorption. In percolating on-site system, the sorption media that have been studied include, but are not limited to, sawdust, peat, compost, zeolite, wheat straw, newspaper, sand, limestone, expanded clay, wood chips, wood fibers, mulch, glass, ash, pumice, bentonite, tire crumbs, expanded shale, oyster shells, and soy meal hulls (Hossain et al. 2010a, b; Xuan et al. 2009). This approach was adjudged to have ''green'' implications because of the inclusion of recycled material as part of the material mixture, promoting treatment efficiency and cost effectiveness (Hossain et al. 2010a).

The ability of a waste biogenic material, the shell of African land snail (*Achatina achatina*), a Gastropod, packed in a column as an on-site system for phosphate removal and recovery has been investigated (Oladoja et al. 2014). The column reactor was operated in a batch-continuous mode, considered as a close approximation to a practical water treatment system, for 30 days, using synthetic phosphate-contaminated water. The time–concentration profile parameters were derived at different influent phosphate concentrations that ranged between 50 and 500 mg/L, and hydraulic residence time (HRT) (6, 12 and 24 h), to determine the performance efficiency of the column reactor. Significant reduction (>90%) of the influent phosphate concentration was achieved at all the HRT. The fractionation of the phosphate within the substrate matrix was performed to assess the potential for application as manure in agricultural practices.

Water treatment residuals (WTRs), coal fly ash (CFA), and granular activated carbon (GAC) were packed in a column and used to abstract the dissolved organic carbon (DOC) and nutrients in a mixture of DOC and nutrient-rich surface water from Western Australia's Swan Coastal Plain. The water was pumped through the columns in a saturated up-flow mode at a constant flow rate of ca. 0.2 mL/min. This flow rate was selected to facilitate an approximately 12-h residence time for influent water within laboratory columns. Influent water and effluents from experimental columns were analyzed for pH, alkalinity, DOC, HCO_3^-, NO_x-N, NH_3-N, TN, soluble reactive P (SRP or PO_4-P), TP, Al, Ca, Cl^-, Fe, Mg, Mn, K, Si, Na, and SO_4^{2-}. The columns were operated to hydraulic failure, or until nutrient and DOC sorption capacities could be determined. Both CaO and $CaCO_3$-based WTRs effectively attenuated inorganic N species, but exhibited little capacity for organic N removal. The CaO-based WTR demonstrated effective removal of DOC and P in column trials, and a high capacity for P sorption in batch experiments. Granular activated carbon proved effective for DOC and dissolved organic nitrogen (DON) removal in column trials, but was ineffective for P diminution. Only CFA demonstrated effective removal of a broad suite of inorganic and organic nutrients. Water treated by filtering through the CaO-based WTR exhibited nutrient ratios characteristic of potential P-limitation with no potential N- or Si-limitation with respect to growth of aquatic biota, indicating that treatment of nutrient-rich water using the CaO-based WTR may result in conditions less favorable for cyanobacterial growth and more favorable for growth of diatoms.

A solid phase denitrification system, ecological floating beds (EFBs) with various substrates, was tested for the purification of hypereutrophic waters under batch and continuous flow conditions (Cao and Zhang 2014). The addition of biodegradable materials as biocarriers and growth substrates to a planted EFB was thought to promote its purification ability and enhance its plant growth environment. A conventional plant-only EFB (EFB-PO) was used as the control system and compared to EFBs using either rice straw (EFB-RS) or plastic filling (EFB-PF) as a substrate for microorganisms. Under the batch condition, the mean removal rates of the EFB-RS for total nitrogen (TN), ammonium nitrogen (NH_4^+-N), and nitrate nitrogen (NO_3^--N) were, respectively, 76.94, 93.50, and 93.18% after 2 days, which represent increases of 43.94, 19.83, 75.24, and 34.76%, 24.67%, and 34.54% over the same values for EFB-PF and EFB-PO, respectively. The results of the continuous flow experiment indicated that the mean removal rates of TN, NH_4^+-N, and NO_3^--N for EFB-RS and EFB-PF were, respectively, 72.21, 88.88, and 80.41%, and 51.85, 86.23, and 58.62% when the hydraulic retention time (HRT) was 24 h.

In wetlands, the majority of nitrogen removal is thought to occur through microbial processes (e.g. nitrification and denitrification) and to a lesser degree, sedimentation, filtration, precipitation, and volatization. Minor fraction of the total reduction of nutrients is thought to occur via plant uptake (Kadlec and Knight 1996; Koottatep and Polprasert 1997; Lin et al. 2002; Haddad et al. 2006). Macrophytes have been reported to play a key role in the performance of freshwater CW, facilitating the nitrification/denitrification process, maintaining the hydraulic conductivity of the substrate, increasing microbial assemblages in the root zone, and participating in nutrient uptake (Brix 1994; Haberl et al. 1995). Like the rhizomes of macrophytes, the roots of salt marsh *Salicornia sp*., possess aerenchyma which allow exchange of gases between the shoot and the root and indirectly aerate the surrounding soil zone potentially resulting in increased nitrification/denitrification efficiency (Brix 1994; Haberl et al. 1995; Faulwetter et al. 2009). Consequently, the effectiveness of constructed wetlands (CW) planted with a halophytic, saltmarsh plant, *Salicornia europaea,* for the treatment of effluent generated from a commercially operating marine fish and shrimp recirculating aquaculture systems (RAS) was evaluated over 88 days (Webb et al. 2012). Nitrogen in the wastewater was primarily in the form of dissolved inorganic nitrogen (TDIN) and was removed by 98.2 ± 2.2% under ambient loadings of 109–383 μmol L^{-1}. A linear relationship was established between TDIN uptake and loading over the range of inputs tested. At peak loadings of up to 8185 ± 590 μmol L^{-1}, the filter beds removed between 30 and 58% of influent TDIN. Influent dissolved inorganic phosphorus levels ranged from 34 to 90 μmol L^{-1}, with 36 to 89% reduction under routine operations. Dissolved organic nitrogen (DON) loadings were lower

(11–144 μmol L^{-1}), and between 23 and 69% of influent DON was removed during routine operation, with no significant removal of DON under high TDIN loading. Over the 88-day study, cumulative nitrogen removal was 1.28 mol m^{-2}, of which 1.09 mol m^{-2} was retained in plant tissue, with plant uptake ranging from 2.4 to 27.0 μmol N g^{-1} dry weight day^{-1}. The high removal efficiency of DIN under ambient nitrogen loading and the significant removal of DIP indicate that constructed wetlands planted with *Salicornia* are well suited to the treatment of batches of highly concentrated wastewater released during routine filter backwashing in marine RAS.

A combined recycling purification system consisting of an aquatic plant filter, bio-zeolite filter, bio-ceramic filter, gravel bed filter, and in situ algal control facility, that included floating plant and a micro-bubble aerator, was built to preserve eutrophic landscape pond water (Chen et al., 2013). The purification system was reported to perform well in pollutant removal and the removal efficiencies of SS, TN, NH_4^+-N, NO_3^--N, NO_2^--N, and PO_4^{3-}-P were all above 50%, with a hydraulic loading rate of 1.2 m/d. The aquatic plant filter captured approximately 38.0% of the SS load while the bio-ceramic filter accounted for 50.9% of COD removal. The gravel bed filter, built for denitrification, eliminated 60.6% of TN load and 62.0% of NO_3^- load. The bioceramic filter made no contributions to TN removal, and the effluent TN and NO_3^- increased by 18.4% and 18.3%, respectively. Aquatic plant filter was the best at NH_4^+-N removal and removed approximately 41.3% of the NH_4^+-N load. Additionally, the aquatic plant filter was located in the main pool of phosphorus and removed approximately 58.4% of TP load and 68.4% of PO_4^{3-}P load. When the purification system was halted, the quality of the pond water rapidly deteriorated in six days. The purification system also demonstrated the ability to remove algae, with a Chl-a removal efficiency of approximately 40–50%.

In a field study conducted by Bryant et al. (2012) on the University of Maryland Eastern Shore Research and Teaching Farm (USA), a filter, containing flue gas desulfurization (FGD) gypsum, (a by-product of coal-fired power generation) medium was constructed within a field ditch to remediate P-laden runoff water from a 17-ha catchment with high P soils for a period more than three years. It was observed that for storm-induced flow, the filter removed about 65% of the total dissolved P (TDP) load for water passing through the filter, whereas a reduction in efficiency to 22% was recorded when bypass flow and base flow were taken into consideration. It was concluded that the filter material was chemically effective at removing P, but that the setup tested is unlikely to be practical at the whole-farm scale due to low P removal efficiencies, particularly during storms when large P loads mostly bypassed the filter. In addition, long-term field testing of the ditch filter demonstrated a need to regularly till the surface of the gypsum filter bed to maintain satisfactory flow rates for adequate P removal.

Penn et al. (2012) reported on the development, installation, and monitoring of a P removal structure to treat golf course runoff from a 320-ha catchment near Stillwater, OK (USA). The P removal structure was filled with steel slag, a by-product of the steel industry, and was located in a drainage ditch at the outlet of the catchment. Penn et al. (2012) monitored a total of 54 runoff events over a period of 5 months in 2010, including 20 resulting from natural rainfall and 34 resulting from irrigation of the golf greens located 130 to 150 m up gradient of the P removal structure. The structure removed about 25% of the total dissolved (TDP) load and the P removal efficiencies were higher for irrigation runoff (62%) than for natural runoff (21%), owing to lower retention times during large flow events produced by heavy rainfall. On the basis of a set of flow-through equations developed by Penn and McGrath (2011) for steel slag, a lifetime of the P removal structure of 16.8 months was predicted, which corresponded reasonably well with the projected lifetime of 15.4 months based on field measurements.

In addition to the various nutrient removal strategy using on-site system, the potential applications of the waste generated from this procedure have also been studied. One such use of the P-saturated substrate is as fertilizer and/or soil conditioner in agriculture, as suggested by Johansson (1998). There are a few studies showing that some substrates, blast furnace slag, for instance, can release sorbed P in a form which is readily available for assimilation by plants (Johansson and Hylander 1998). Other experiments used P-saturated blast furnace slag as fertilizer in a pot experiment which demonstrated promising results (Hylander and Simá n 2001). Krogstad and Jensen (1999) conducted a similar experiment testing LWA products. They concluded that a disproportionately large amount of P-saturated light-weight product must be added to the pots before the plants could assimilate the phosphorus. Krogstad and Jensen (1999), however, stressed that a light-weight product, more developed, most probably should show a better result

Micro pollutants

The presence of micro pollutants (e.g. biphenyls, detergents, dyes, fertilizers, greases, hydrocarbons, oils, pharmaceuticals, personal care products, pesticides, plasticizers, phenols, and surfactants) in aqua system has prompted the development of efficient, applicable, and affordable technologies, in particular, in remote, low-income communities. The use of metallic iron (Fe^0) beds has been demonstrated as such an appropriate technology (Ghauch 2015; Noubactep et al. 2009; Litter et al. 2010; Noubactep 2010a; Noubactep and Schöner 2010; Giles et al. 2011; Noubactep 2013a) and design criteria presented (Noubactep and Caré 2010; Noubactep et al. 2012a, b; Bilardi et al. 2013a, b; Caré et al. 2013; Btatkeu-K et al. 2014). The suitability of Fe^0 to treat a complex mixture of micro-pollutants arises from the fact that the primary removal mechanism is not a specific one. Concomitant occurrence of adsorption and co-precipitation in the removal of biological and chemical contaminants from aqua phase has been reported (Ghauch 2013; Noubactep 2010b, 2013b and 2014). Additionally, in column systems, in situ generation of volumetric expansive corrosion products enhances size-exclusion (Ghauch 2013; Noubactep 2011). The specificity of Fe^0/H_2O systems for contaminant removal is of secondary nature as it arises not from the redox properties of Fe^0 ($E^0 = -0.44$ V) but from the adsorptive affinity of dissolved species for various iron oxides (Ghauch 2013; Noubactep, 2010c; Sato, 2001).

Peat, a partially fossilized plant matter which occurs in wet anoxic system, has been used repeatedly as a reactive material in an on-site system. Peat is a rather complex material containing lignin which bears polar functional groups such as alcohols, aldehydes, ketones, acids, phenolic hydroxides, and ethers that can be involved in chemical bonding. Because of the very polar character of this material, the specific adsorption for dissolved solids such as transition metals and polar organic molecules is reported to be quite high (Coupal and Lalancette 1976). It has been reported that peat is very effective in the removal of textile dyes (Poots et al. 1975; Stephen et al. 1988); Pesticides (Brown et al. 1979, Williams and Crawford 1983; Cloutier et al. 1984); heavy metals (Coupal and Lalancette 1976; Smith et al. 1977; Chancy and Hundemann 1979); oily compounds (Mathavan and Vivaraghavan 1989); and radioactive materials (Belanger et al. 1987).

Operating requirements of on-site system scheme

The basic objectives of a household or neighborhood domestic wastewater management system have been summarized thus (Sandec Report No. 14/06):

Protection of public Health

A domestic wastewater management system should create an effective physical barrier between contaminated wastewater and user, as well as avoid odor emissions and stagnant water leading to breeding sites for mosquitoes.

Protection of the Environment

A domestic wastewater management system should prevent euthrophication and pollution of sensitive aquatic systems (surface water, groundwater, drinking water reservoirs) as well as terrestrial systems (irrigated soil).

Ensuring soil fertility

If domestic wastewater is reused in irrigation, groundwater recharge or landscaping, appropriate management should minimize short- or long-term impacts on soil (soil degradation, clogging, salinization)

Socioculturally and economically acceptable

Domestic wastewater management systems have to be adapted to the socio-cultural and economic settings of the household or neighborhood. If waste reuse is culturally not anchored, for example, domestic wastewater management systems aiming at vegetable garden irrigation are likely to fail.

Simple and user friendly

Household or neighborhood domestic wastewater management systems should be manageable by the user, technically simple and robust, and possibly not rely on external fuel, power supply or chemicals.

Compliance with national and international regulations and standards

Qualitative and quantitative effluent standards have to maintain or even enhance the quality of receiving waters, to ensure soil fertility, and protect public health. If domestic wastewater is appropriately treated, these standards will generally be easily met.

Effluent quality monitoring

In order to comply with the recommended qualitative and quantitative effluent discharge standards, a well-equipped water and wastewater analytical laboratory should be established in proximate locations. It should be noted that in the under-resourced regions of the world, guidelines on the discharge and reuse standards are often unknown to the majority of the inhabitants and the cost of laboratory analysis are often unaffordable. In order to ensure compliance with the recommended guidelines and standards, information on discharge and reuse standards should be made available to the operators and the cost of laboratory analysis should be highly subsidized or borne by a third party. The importance of well-equipped laboratory in the developing world as a prelude to safe water delivery and improved environmental sanitation has been previously recognized (Tepong-Tsindé, et al., 2015, Ndé-Tchoupé, et al., 2015).

Management of On-Site System Scheme

Like any technology, the success of on-site system is usually assumed to be solely dependent upon the adoption of proper management strategies. Considering the non-conventional posture of the on-site system, cultural and geographical consideration is also a pertinent factor to consider if the acceptability and sustainability of the system is to be ensured. Specifically, six areas of responsibility have been identified as essential to on-site system effectiveness (Ruiter, 1981): Planning (e.g. subdivision layout); Site evaluation (e.g. percolation test); Design (e.g. leachfield sizing); Installation (e.g. system construction); Operation (e.g. loading); Maintenance (e.g. septage pumping)

Traditionally, the responsibility for the first four functions has been assumed by local or regional health departments, while operation and maintenance have been left to the home owners. Dix and Ward (1978) opined that since homeowners' attitude to the assumption of these responsibilities in a conscientious manner is apathetic, septic system has not always been viewed as a viable, permanent approach to wastewater treatment and disposal. Ward, 1984 surmised that if professional operation and management is provided, there is no reason why on-site technology cannot be considered a long-term, permanent wastewater treatment option, capable of being expanded as the community grows. With small flow systems being proposed more often as an alternative, communities are beginning to develop the organizational structures that permit the small systems to receive professional operation and maintenance techniques. Ward, 1984 also identified that the provision of central operation and maintenance has been hindered by a lack of definition as to the specific operation and maintenance required and the cost involved.

Considering the challenges in the under-resourced regions of the world, the use of operation and maintenance professional may not be workable because of the communal lassitude towards such professionals and the cost implication on the part of the homeowners.

In the under-resourced regions, in order to get the homeowners and community members to participate in the operation and maintenance of on-site facilities there is need for a reorientation on the danger inherent in poor management of this wastewater and the need to adopt the recommended procedure for the management. The system owners and operators should also be conscious of the fact that the limit of scale of the on-site system is limited and not limitless. This is because on-site treatment systems sited in residential densities that exceed the treatment capacity of the reactive medium can create many other unforeseen challenges.

Conclusion

In order to assuage the scourge of water pollution challenges emanating from improper handling of domestic wastewater, the under-resourced regions of the world require the use of high-performance, economical, technologically simple, reliable, and low-energy consuming appropriate technology for the management of domestic wastewater. Gravity percolation of wastewater through reactive material is one such on-site system that has been tested and found to be an effective appropriate technology for the under-resourced regions. On the strength of the high-performance efficiencies of the gravity percolating filter in the attenuation of array of pollutants (physico-chemical parameters, nutrients, and micro pollutants) found in domestic wastewater, at the laboratory and field study, the on-site treatment scheme is an appropriate technology for domestic wastewater treatment. The operation and sustainability are dependent on strict adherence to the operating requirements and best management practices of on-site treatment schemes.

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